M. L. Nichols

PROBLEMS

IN

INORGANIC CHEMISTRY

BY

L. M. DENNIS

PROFESSOR OF INORGANIC CHEMISTRY
CORNELL UNIVERSITY

ITHACA, NEW YORK
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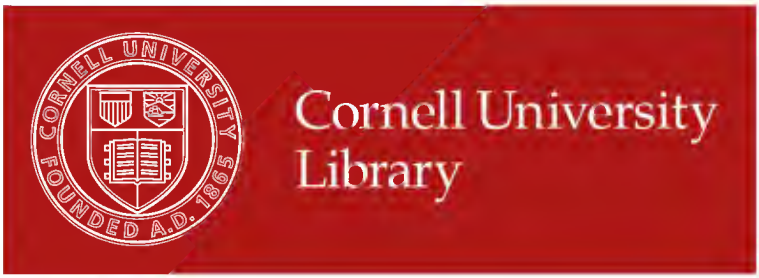

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TABLE OF ATOMIC WEIGHTS

(From Report of International Committee on Atomic Weights)

1914

Aluminum	Al	27.1	Molybdenum	Mo	96.0
Antimony	Sb	120.2	Neodymium	Nd	144.3
Argon	A	39.88	Neon	Ne	20.2
Arsenic	As	74.96	Nickel	Ni	58.68
Barium	Ba	137.37	Niton	Nt	222.4
Bismuth	Bi	208.0	Nitrogen	N	14.01
Boron	B	11.0	Osmium	Os	190.9
Bromine	Br	79.92	**Oxygen**	**O**	**16.00**
Cadmium	Cd	112.4	Palladium	Pd	106.7
Caesium	Cs	132.81	Phosphorus	P	31.04
Calcium	Ca	40.09	Platinum	Pt	195.2
Carbon	C	12.00	Potassium	K	39.10
Cerium	Ce	140.25	Praseodymium	Pr	140.6
Chlorine	Cl	35.46	Radium	Rd	226.4
Chromium	Cr	52.0	Rhodium	Rh	102.9
Cobalt	Co	58.97	Rubidium	Rb	85.45
Columbium	Cb	93.5	Ruthenium	Ru	101.7
Copper	Cu	63.57	Samarium	Sa	150.4
Dysprosium	Dy	162.5	Scandium	Sc	44.1
Erbium	Er	167.7	Selenium	Se	79.2
Europium	Eu	152.0	Silicon	Si	28.3
Fluorine	F	19.0	Silver	Ag	107.88
Gadolinium	Gd	157.3	Sodium	Na	23.00
Gallium	Ga	69.9	Strontium	Sr	87.63
Germanium	Ge	72.5	Sulphur	S	32.07
Glucinum	Gl	9.1	Tantalum	Ta	181.5
Gold	Au	197.2	Tellurium	Te	127.5
Helium	He	3.99	Terbium	Tb	159.2
Holmium	Ho	163.5	Thallium	Tl	204.0
Hydrogen	H	1.008	Thorium	Th	232.4
Indium	In	114.8	Thulium	Tm	168.5
Iodine	I	126.92	Tin	Sn	119.0
Iridium	Ir	193.1	Titanium	Ti	48.1
Iron	Fe	55.84	Tungsten	W	184.0
Krypton	Kr	82.92	Uranium	U	238.5
Lanthanum	La	139.0	Vanadium	V	51.0
Lead	Pb	207.1	Xenon	Xe	130.2
Lithium	Li	6.94	Ytterbium	Yb	172.0
Lutecium	Lu	174.0	Yttrium	Yt	89.0
Magnesium	Mg	24.32	Zinc	Zn	65.37
Manganese	Mn	54.93	Zirconium	Zr	90.6
Mercury	Hg	200.6			

THE PERIODIC TABLE OF THE ELEMENTS

Series	Zero Group	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII		
		R_2O	R_2O_2	R_2O_3	R_2O_4 RH_4	R_2O_5 RH_3	R_2O_6 RH_2	R_2O_7 RH	R_2O_8		
1		Hydrogen H = 1.008									
2	Helium He = 4.0	Lithium Li = 7.0	Glucinum Gl = 9.1	Boron B = 11.0	Carbon C = 12.0	Nitrogen N = 14.01	Oxygen O = 16.00	Fluorine F = 19.0			
3	Neon Ne = 20	Sodium Na = 23.0	Magnesium Mg = 24.3	Aluminum Al = 27.1	Silicon Si = 28.3	Phosphorus P = 31	Sulphur S = 32	Chlorine Cl = 35.5			
4	Argon Ar = 39.9	Potassium K = 39.10	Calcium Ca = 40.1	Scandium Sc = 44.1	Titanium Ti = 48.1	Vanadium V = 51	Chromium Cr = 52	Manganese Mn = 55	Iron Fe = 55.8	Nickel Ni = 58.7	Cobalt Co = 59
5		Copper Cu = 63.6	Zinc Zn = 65.4	Gallium Ga = 70	Germanium Ge = 72.5	Arsenic As = 75	Selenium Se = 79.2	Bromine Br = 79.9			
6	Krypton Kr = 83.0	Rubidium Rb = 85.45	Strontium Sr = 87.6	Yttrium Y = 89	Zirconium Zr = 90.6	Columbium Cb = 93.5	Molybdenu Mo = 96	—	Ruthenium Ru = 101.7	Rhodium Rh = 102.9	Palladium Pd = 106.7
7		Silver Ag = 107.88	Cadmium Cd = 112.4	Indium In = 114.8	Tin Sn = 119.0	Antimony Sb = 170.2	Tellurium Te = 127.5	Iodine I = 126.92			
8	Xenon Xe = 130.2	Caesium Cs = 132.8	Barium Ba = 137.4	Lanthanum La = 139	Cerium Ce = 140.25		—		—	—	—
9		—	—		—	—	—	—			
10	—	—	—	Ytterbium Yb = 172.0	—	Tantalum Ta = 181.5	Tungsten W = 184	—	Osmium Os = 190.9	Iridium Ir = 193.1	Platinum Pt = 195.2
11		Gold Au = 197.2	Mercury Hg = 200.6	Thallium Tl = 204	Lead Pb = 207.10	Bismuth Bi = 208	—	—			
12	—	—	Radium Rd = 226.4	—	Thorium Th = 232.4	—	Uranium U = 238.5				

TABLE OF METRIC MEASURES WITH ENGLISH EQUIVALENTS

Measures of Length

1 Millimeter, mm.		= .03937 inch.	
1 Centimeter, cm.	= 10 mm.	= .3937 "	
1 Decimeter, dm.	= 10 cm.	= 3.9370 inches.	
1 Meter, m.	= 10 dm.	= 39.3708 "	= 3.2808 feet.
1 Kiolmeter, km.	= 100 m.	= .6214 mile.	

Measures of Volume

1 Cubic Centimeter, cc. = .06103 cu. inches, or .03381 U. S. fluid oz.

1 Cubic Decimeter (Liter), 1, = 1000 cc. = { 61.027 cu. inches / 1.057 U. S. qts. } or .2642 U. S. gallon.

1 Cubic Meter = 1000 l. = 35.3166 cu. feet.

Measures of Weight

1 Milligram		= .0154 grain.
1 Gram	= 1000 mg.	= 15.432 grains, or .03215 oz. troy, or .03527 oz. av.
1 Kilogram (kilo)	= 1000 grams.	= 2.2046 lbs. av.

Common English Measures with Metric Equivalents

1 Inch	= 25.399 millimeters.	1 Cu. inch	= 16.386 cubic centimeters.
1 Foot	= .3048 meter.	1 Cu. foot	= 28.315 liters.
		1 Quart	= .9464 "
1 Mile	= 1.609 kilometers.	1 Gallon	= 3.7854 "
		1 Grain	= .0648 gram.
		1 Ounce Av.	= 28.3495 grams.
		1 Lb. Av.	= 453.59 grams.
		1 Ton (2000 lbs.)	= 907.18 kilograms.

Apothecaries' Weights and Measures with Metric Equivalents

1 Grain	= .0648 gram.	1 Minim	= .0616 cc.
1 Scruple	= 1.296 grams.	1 Fluid Drachm	= 3.6965 cc.
1 Drachm	= 3.888 grams.	1 Fluid Ounce	= 29.572 cc.
1 Oz. Troy	= 31.1035 grams.	1 Pint	= 473.1 cc.
1 Lb. Troy	= 373.2418 grams.		

Area

10,000 Square Centimeters	= 1 sq. meter = 10.764 sq. ft.
1 Square Centimeter	= .1550 square inch.
1 Square Foot	= .0929 square meter.
1 Square Inch	= 6.4516 square centimeters

CONVERSION FACTORS

To Change	To	Multiply by
Inches	Centimeters	2.54
Feet	Meters	.305
Miles	Kilometers	1.609
Meters	Inches	39.37
Kilometers	Miles	.621
Square inches	Square centimeters	6.452
Square yards	Square meters	.836
Square centimeters	Square inches	.155
Square meters	Square yards	1.196
Cubic inches	Cubic centimeters	16.386
Cubic yards	Cubic meters	.765
Cubic centimeters	Cubic inches	.061
Cubic meters	Cubic yards	1.308
Fluid ounces	Cubic centimeters	29.572
Quarts	Liters	.946
Cubic centimeters	Fluid ounces	.034
Liters	Quarts	1.057
Grains	Milligrams	64.799
Ounces (av.)	Grams	28.35
Pounds (av.)	Kilograms	.454
Ounces (troy)	Grams	31.103
Grams	Grains	15.432
Kilograms	Pounds	2.205

THEORETICAL DENSITIES OF GASES AND WEIGHT OF ONE LITER OF EACH

at 0° and 760 mm. pressure

Substance	Formula	Molecular Weight	Density Air = 1	Weight of 1 liter in grams Latitude 45° at sea-level
Acetylene	C_2H_2	26.02	0.898	1.162
Ammonia	NH_3	17.03	0.589	0.762
Arsine	AsH_3	78.02	2.696	3.485
Bromine	Br_2	159.92	5.525	7.143
Butane	C_4H_{10}	58.08	2.006	2.594
Carbon dioxide	CO_2	44.00	1.520	1.965
Carbon monoxide	CO	28.00	0.967	1.251
Carbon oxysulphide	COS	60.06	2.075	2.682
Carbonyl chloride	$COCl_2$	98.90	3.417	4.417
Chlorine	Cl_2	70.90	2.449	3.167
Cyanogen	C_2N_2	52.02	1.799	2.326
Ethane	C_2H_6	30.05	1.038	1.342
Ethylene	C_2H_4	28.03	0.968	1.252
Hydrogen	H_2	2.016	0.069	0.0899[1]
Hydrogen bromide	HBr	80.97	2.797	3.616
Hydrogen chloride	HCl	36.46	1.259	1.628
Hydrogen fluoride	HF	20.00	0.691	0.894
Hydrogen iodide	HI	127.98	4.417	5.711
Hydrogen sulphide	H_2S	34.08	1.177	1.523
Methane	CH_4	16.03	0.554	0.716
Nitric oxide	NO	30.01	1.038	1.342
Nitrogen	N_2	28.02	0.970	1.254
Nitrous oxide	N_2O	44.02	1.523	1.969
Oxygen	O_2	32.00	1.105	1.429
Phosphine	PH_3	34.02	1.175	1.520
Propane	C_3H_8	44.06	1.522	1.966
Propylene	C_3H_6	42.05	1.453	1.878
Sulphur dioxide	SO_2	64.06	2.213	2.861
Water vapor	H_2O	18.016	0.622	0.804
Atmospheric air			1.000	1.293

[1] In answering the problems in this book, use 0.09 gram as the weight of one liter of hydrogen.

CHEMICAL PROBLEMS

CORRECTION OF GAS VOLUMES

If a gas at 0°C. be warmed to 1 C. (the pressure remaining the same) it will expand $\frac{1}{273}$ of the volume that it occupied at 0°. For each additional rise of 1°C. there will be an increase in volume of $\frac{1}{273}$ of the volume of the gas at 0°. Consequently, if the temperature of a gas is raised from 0°C. to 273°C. its volume will be doubled.

If a gas be cooled from 0°C. to —1°C. there will be a decrease of $\frac{1}{273}$ of its volume, and for each additional fall of 1°C. there will be a decrease in the volume of $\frac{1}{273}$ of the volume of the gas at 0°. Consequently it would seem that if a gas were cooled down to 273° below the Centigrade zero, its volume would be zero. This is manifestly impossible, yet for convenience we use this temperature, —273°C., as the starting point in temperature calculations and term it the ABSOLUTE ZERO. Temperatures measured from this absolute zero are termed *absolute temperatures*. Thus, 0°C. is 273° above zero in terms of absolute temperature.

LAW OF CHARLES. *Provided the pressure remains constant, the volume of a gas varies directly as its absolute temperature.*

If T and T_1 be two different absolute temperatures and V and V_1 be the volumes of a gas corresponding to these temperatures, then

(1) $V : V_1 = T : T_1$

Again, the volume of a gas changes as the pressure to which it is subjected is changed.

LAW OF BOYLE. *Provided the temperature remains constant, the volume of a gas is inversely proportional to the pressure.*

If P and P_1 be two different pressures and V and V_1 be the volumes of a gas corresponding to these pressures, then

(2) $V : V_1 = P_1 : P$

Volumes of gases can not be compared unless the temperature and pressure under which the gases were measured are stated, or unless the volumes are corrected according to some arbitrary standard. The latter is the simpler procedure and consequently it is employed. The arbitrary standard adopted by scientists in

stating the volume of a gas is the volume that the gas would occupy under "*standard conditions,*" that is, at a temperature of 0°C. (273° absolute temperature) and under a pressure of 760 millimeters of mercury.

In reducing an observed gas volume to the volume which the gas would occupy if under standard conditions, the following procedure may be used.

If V represents the volume under standard conditions, V_1 the observed volume, T the absolute temperature under standard conditions (273°), and T_1 the observed absolute temperature, then from (1) we may ascertain the volume that a gas at a temperature T_1 would occupy at the standard temperature T, by multiplying the observed volume by

$$\frac{T}{T_1}$$

If P represents the standard pressure (760 mm.) and P_1 the observed barometric pressure, we may ascertain the volume that the gas would occupy at standard pressure by multiplying the observed volume by

$$\frac{P_1}{P}$$

To make these two corrections simultaneously, it is only necessary to multiply the observed volume by both of these expressions.

$$(3) \quad V = V_1 \frac{T}{T_1} \frac{P_1}{P}$$

Suppose, for example, one were asked to ascertain the volume, under standard conditions, of a gas that measures 110 cc. at 57° C. and under a pressure of 740 mm.

In this case $V_1 = 110$; $T = 273$; $T_1 = 330$ (since 57° C. is 330 above the absolute zero); $P = 760$; and $P_1 = 740$. Substituting these values in (3)

$$V = 110 \quad \frac{273 \times 740}{330 \times 760} = 88.6 \text{ cc.}$$

Conversely, if we know the volume (V) of a gas measured under standard conditions, and wish to ascertain what volume (V_1) it would occupy at any other temperature and pressure, we may use the following equation which is derived directly from (3).

$$(4) \quad V_1 = V \frac{T_1}{T} \frac{P}{P_1}$$

1. A volume of air at 0° measures 90 cc. What would be its volume at 182°? Ans. 150 cc.

2. A volume of air at 182° measures 125 cc. At what temperature would the volume be 100 cc.? Ans. 91°.

3. A volume of air at 91° measures 800 cc. What would be its volume at standard temperature? Ans. 600 cc.

4. If a gas be cooled from +91° to —91°, to what extent will its volume contract? Ans. ½.

5. An open vessel is heated from 0° to 546°. What portion of the air that it at first contained now remains? Ans. ⅓.

6. A volume of air at 45.5° measures 70 cc. What would be its volume at 91°? Ans. 80 cc.

7. 360 cc. of air at 0° is warmed to 22¾°. What is then its volume? Ans. 390 cc.

8. 360 cc. of oxygen at 10° is warmed to 22¾°. What is then its volume? Ans. 376.2 cc.

9. To what temperature must one liter of hydrogen at +87° be cooled to reduce its volume to 500 cc.? Ans. —93°.

10. A volume of air at 17° measures 290 cc. What would be its volume at 77°? Ans. 350 cc.

11. A volume of oxygen at +27° measures 150 cc. What would be its volume at —23°? Ans. 125 cc.

12. A volume of air at 0° measures 1 liter; what would be its volume at 18°? Ans. 1065.9 cc.

13. A volume of air measures 90 cc. under a pressure of 760 mm. What would be the volume under a pressure of 570 mm.? Ans. 120 cc.

14. A sample of hydrogen measures 102 cc., the pressure being 750 mm. What would be the volume of the gas if the pressure were changed to 765 mm. Ans. 100 cc.

15. A volume of air measures 9 liters at a pressure of 780 mm. At what pressure would its volume be 10 liters? Ans. 702 mm.

16. If 10 liters of hydrogen, measured at standard pressure, were forced into a cylinder of one liter capacity, what pressure would the gas then exert? Ans. 7.6 meters.

17. A volume of gas that measured 170 cc. at 740 mm. pressure was afterwards found to measure 185 cc. What was the height of the barometer at the time of the second measurement?
Ans. 680 mm.

18. A volume of gas measures 150 cc. when the barometer stands at 745 mm. What would be the volume at standard pressure? Ans. 147.04 cc.

19. A volume of hydrogen measured 200 cc. when the barometer stood at 768 mm. What would be the volume at 755 mm. pressure? Ans. 203.44 cc.

20. The air in a bottle is pumped out until the pressure drops from 750 mm. to 150 mm. What portion of the air has been removed? Ans. $\frac{4}{5}$.

21. A volume of nitrogen in a eudiometer tube over mercury measures 62 cc., the mercury in the tube standing at a height of 8.3 cm.; the barometer stands at 75.8 cm. Reduce the volume to standard pressure. Ans. 55.07 cc.

22. A eudiometer tube contains a volume of gas measuring 102 cc.; the mercury outside the tube stands 17 cm. above the level on the inside, the barometer indicating meanwhile a pressure of 740 mm. Reduce the volume to standard pressure.
Ans. 122.13 cc.

23. A volume of gas in a eudiometer measures 242 cc. The mercury in the tube stands 18 mm. above that outside. Barometer 740 mm., temperature, 18°C. Reduce to standard volume.
Ans. 215.68 cc.

24. A volume of gas in a tube measures 72 cc. The mercury n the tube stands at the same level as that on the outside. Baromieter, 737 mm.; temperature, 17°C. What would be the volume under standard conditions? Ans. 65.7 cc.

25. The volume of gas in a eudiometer measures 68 cc., the level of the mercury in the tube and trough being the same. The barometer indicates an atmospheric pressure of 739 mm. The

temperature is 20°C. What would be the volume of the gas at 0°C. and under 760 mm. pressure? Ans. 61.61 cc.

26. The volume of gas contained in a tube measures 76 cc. The mercury in the tube stands at a height of 17 mm. Barometer indicates a pressure of 752 mm. The temperature is 17°C. What would be the volume of the gas under standard conditions?

Ans. 69.19 cc.

27. The volume of a gas contained in a tube measures 86 cc., the mercury standing at a height of 34 mm. in the tube. Barometric pressure, 742 mm.; temperature, 23°C. What would be the volume of the gas under standard conditions?

Ans. 73.89 cc.

28. One liter of oxygen at 0° and 760 mm. pressure weighs 1.429 grams. What will one liter weigh at the same temperature with the barometer standing at 780 mm.?

Ans. 1.466 grams.

29. What will be the weight of one liter of oxygen at 0° under a pressure of 740 mm.? Ans. 1.392 grams.

30. At what pressure will one liter of oxygen at 0° weigh one gram? Ans. 531 mm.

31. What will be the weight of one liter of oxygen at 18° and with the barometer at 730 mm.? Ans. 1.288 grams.

32. Under standard pressure, at what temperature will 1 liter of oxygen weigh 1 gram? Ans. 117.1°.

33. Under standard temperature, at what pressure will one liter of hydrogen weigh one gram? Ans. 8444.4 mm.

34. One liter of air at standard pressure and temperature weighs 1.293 grams. Under what pressure will the same volume weigh 2 grams? Ans. 1175.5 mm.

35. If steam is passed over red-hot iron and six grams of hydrogen is set free, what weight of water has been decomposed?

Ans. 53.62 grams.

36. If 200 grams of steam is passed over red-hot iron, what weight of hydrogen will be set free? Ans. 22.38 grams.

37. A tube containing copper oxide weighs 75 grams. This tube is heated to redness, and hydrogen is passed through it. When cooled, the tube is again weighed, and its weight is now found to be 72 grams. What weight of hydrogen has united with the oxygen of the copper oxide? What weight of water has been formed? Ans. Weight of hydrogen, 0.378 gram.
Weight of water, 3.378 grams.

38. Hydrogen is passed over hot copper oxide as in the preceding problem, and the water that is formed is absorbed by calcium chloride and its weight ascertained to be three grams. What has been the loss of weight of the tube containing the copper oxide?
Ans. 2.66 grams.

39. If a tube containing copper oxide weighs, before hydrogen is passed through it, 15.846 grams, and after the hydrogen has been passed, 12.239 grams, how many liters of hydrogen have united with the oxygen of the copper oxide? Ans. 5.049 liters.

How much water has been formed? Ans. 4.061 grams.

WEIGHT AND PERCENTAGE COMPOSITION

Each chemical element is represented by a symbol. The symbol denotes an atom of the element. The actual weights of the atoms have not been ascertained, but we do know their relative weights referred to the weight of an atom of oxygen. These relative weights of the atoms of the elements are termed the *atomic weights* of the elements. (See Table of Atomic Weights on page 3.) The atomic weight of oxygen is 16, and that of hydrogen is 1.008. A molecule of water consists of two atoms of hydrogen united to one atom of oxygen and is represented by the formula H_2O. Consequently, water is made up of $2 \times 1.008 = 2.016$ parts by weight of hydrogen and 16 parts by weight of oxygen. A molecule of hydrogen chloride (HCl) is made up of 1.008 parts by weight of hydrogen, and 35.46 (the atomic weight of chlorine) parts by weight of chlorine. A molecule of potassium chlorate ($KClO_3$) is made up of 39.10 (the atomic weight of potassium, K) parts by weight of potassium, 35.46 parts by weight of chlorine, and $3 \times 16 = 48$ parts by weight of oxygen. The sum of the weights of all the atoms in a compound is termed the *molecular weight* of the compound.

When substances undergo chemical change, there are formed other substances possessing properties different from those of the original bodies. A chemical equation is a brief expression of chemical change. Since matter is never created nor destroyed, it follows that the total weight of the reacting substances must equal the total weight of the products of the reaction, or, in other words, the number of atoms of each element must be the same on both sides of the equation.

For example, when hydrochloric acid is added to a solution of sodium hydroxide, the reaction may be expressed by the equation:

$$NaOH + HCl = NaCl + H_2O.$$

The equation indicates not only that sodium hydroxide and hydrochloric acid react to form sodium chloride and water, but also that $23 + 16 + 1.008 = 40.008$ parts by weight of NaOH, and $1.008 + 35.46 = 36.468$ parts of HCl, combine to form $23 + 35.46 = 58.46$ parts NaCl and $2.016 + 16 = 18.016$ parts

H_2O. If now we wish to know how much sodium chloride may be prepared from any given weight, say 100 grams, of sodium hydroxide by adding hydrochloric acid to the latter, we use the simple proportion 40.008 : 58.46 = 100 : x. x = 146.1 grams. In similar manner we may calculate the weight of a product resulting from other cases of chemical change, or, conversely, the weight of the reacting substance needed to yield a given weight of a product.

If a product of a reaction is gaseous under standard conditions, the volume of that product may be ascertained by first calculating the weight of the substance that is produced and then dividing this weight by the weight of a unit volume of the substance. For example, to find what number of liters of hydrogen is produced when 100 grams of water is decomposed by electrolysis, the weight of the hydrogen that is formed is first calculated from the proportion

$$H_2O\ (2.016 + 16 = 18.016)\ : 2\ H\ (2.016) = 100 : x.$$

x = 11.19 grams. One liter of hydrogen under standard conditions weighs .0899 gram. Consequently, 11.19 grams of hydrogen would, under standard conditions, have a volume of 124.47 liters.

NOTE:—In answering the problems use 0.09 gram as the weight of one liter of hydrogen.

40. What weight of hydrogen can be obtained from 18.016 grams of water? Ans. 2.016 grams.

41. What volume of hydrogen can be obtained from 900.8 grams of water? Ans. 1120 liters.

42. What weight of hydrogen can be obtained from 10 grams of water? Ans. 1.119 grams.

43. What volume of hydrogen can be obtained from one kilogram of water? Ans. 1243.33 liters.

44. With what weight of hydrogen will 30 grams of oxygen unite to form water? Ans. 3.78 grams.

45. What volume of hydrogen results when 18 grams of zinc is treated with sulphuric acid? Ans. 6.16 liters.

46. With how much sulphuric acid must zinc be treated in order to obtain 16250 cc. of hydrogen. Ans. 71.15 grams.

47. What weight of zinc sulphate would be formed in the preceding? Ans. 117.13 grams.

48. What volume of hydrogen would be evolved when zinc reacts with a solution of hydrochloric acid that contains 327 grams of hydrogen chloride? What weight of zinc chloride will be formed? Ans. 100.45 liters.
611.25 grams $ZnCl_2$.

49. A balloon of 100,000 liters capacity is to be filled with hydrogen; how many kilograms of zinc and sulphuric acid will be needed? Ans. Zn, 291.3 kilograms; H_2SO_4, 437.8 kilograms.

50. How much water could be decomposed by 20.7 grams of sodium, and what volume of hydrogen would be set free?
Ans. 16.2 grams H_2O, 10.08 liters of hydrogen.

51. What volume of hydrogen will unite with 24 grams of oxygen to form water? Ans. 33.6 liters.

52. What volume of hydrogen and of oxygen could be obtained by electrolysis of 10 grams of water? Ans. 6.22 liters oxygen.
12.43 liters hydrogen.

53. If 23 grams of sodium acts upon water, what volume of hydrogen will be produced? Ans. 11.1 liters.

54. What weight of sodium would be needed to produce, by the decomposition of water, one liter of hydrogen?

Ans. 2.058 grams.

55. What weight of oxygen can be obtained by heating 54 grams of mercuric oxide, HgO? Ans. 4 grams.

56. How much mercuric oxide must be heated in order to obtain 2 grams of oxygen? Ans. 27 grams.

57. With what weight of mercury will 16 grams of oxygen unite to form mercuric oxide? Ans. 200 grams.

58. What weight of oxygen is contained in 25 grams of potassium chlorate, $KClO_3$? Ans. 9.78 grams.

59. Calculate the percentage of oxygen by weight in mercuric oxide, HgO; manganese dioxide, MnO_2; potassium chlorate, $KClO_3$; and water, H_2O.

Ans. HgO, 7.41 per cent; $KClO_3$, 39.15 per cent; MnO_2, 36.78 per cent; H_2O, 88.81 per cent.

60. What weight of potassium and what weight of chlorine are contained in 17 grams of potassium chlorate?

Ans. K = 5.43 grams, Cl = 4.91 grams.

61. How much potassium chloride would result upon highly heating 35 grams of potassium chlorate? Ans. 21.3 grams.

62. How much potassium chlorate must be heated in order to obtain 14 grams of oxygen? Ans. 35.76 grams.

63. How much potassiun chlorate must be used to fill a gasometer of ten liters capacity with oxygen, when the temperature is 20° and the baromctric pressure is 750 mm.? Ans. 33.52 grams.

64. If potassium chlorate costs 80 cts. per kilogram, what will be the cost of enough to make 500 grams of oxygen gas?

Ans. $1.02.

65. What weight of sodium will be necessary to decompose 15 grams of water? Ans. 19.19 grams.

What weight of hydrogen will be formed? Ans. 1.68 grams.

66. What weight of phosphorus would be needed to combine with 700 cc. of oxygen to form phosphorus pentoxide, P_2O_5?

Ans. 0.77 gram.

67. If one gram of hydrogen and one gram of oxygen are mixed and the mixture then ignited, what weight of water will be formed? What volume of gas will remain uncombined?

Ans. 1.126 grams; 9.71 liters.

68. What weight of oxygen will unite to form water with a volume of hydrogen that measures 1250 cc. at 740 mm. and 18°C.?

Ans. 0.8155 gram.

69. A glass tube containing copper oxide weighed 56.5 grams. After heating it to redness and passing hydrogen through it until all the CuO was reduced to metal, the weight of the tube and contents was found to be 48.5 grams. What weight of water was formed, and how much copper oxide did the tube at first contain?

Ans. H_2O, 9.008 grams; CuO, 39.8 grams.

70. If 10 cc. of water is completely decomposed by electrolysis in a room in which the pressure is 755 mm., and the temperature is 21°C., what will be the volume of the hydrogen that is formed?

Ans. 13.48 liters.

71. How much weight will 32.2 grams crystallized sodium sulphate, $Na_2SO_4 \cdot 10\ H_2O$, lose on heating? Ans. 17.99 grams.

72. How many grams of dry sodium carbonate is contained in one pound of crystallized washing soda, $Na_2CO_3 \cdot 10\ H_2O$?

Ans. 168.25 grams.

73. How many pounds of Plaster of Paris, $(CaSO_4)_2 \cdot H_2O$ can be made by calcining 10 kilograms of gypsum, $CaSO_4 \cdot 2\ H_2O$?

Ans. 18.59 pounds.

74. How many kilograms of water will be set free when one ton of crystallized copper sulphate, $CuSO_4 \cdot 5\ H_2O$, is converted to the anhydrous condition by heating? Ans. 327.51 kilograms.

75. What weight of nitric acid will be produced by highly heating 75 grams of Chile saltpeter, $NaNO_3$, with an excess of concentrated sulphuric acid? Ans. 55.56 grams.

76. What weight of sulphuric acid and sodium nitrate should be taken in order to obtain 215 grams of nitric acid?

$$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3.$$

Ans. H_2SO_4, 334.61 grams.

$NaNO_3$, 290.2 grams.

77. What weight of primary sodium sulphate will be formed in the preceding reaction? Ans. 409.81 grams.

78. From what weight of potassium nitrate can 25 grams of nitric acid be obtained by treatment with sulphuric acid?

Ans. 40.13 grams.

79. If 78 grams of copper nitrate, $Cu(NO_3)_2$, is decomposed by concentrated sulphuric acid, what weight of nitric acid and what weight of copper sulphate will be formed?

Ans. 52.397 grams HNO_3.
66.376 grams $CuSO_4$.

80. If copper and nitric acid react as expressed in the equation:

$$3\,Cu + 8\,HNO_3 = 3\,Cu(NO_3)_2 + 2\,NO + 4\,H_2O,$$

what weight of metallic copper should be taken if one kilogram of copper nitrate is to be formed in this manner?

Ans. 338.98 grams.

81. What weight of metallic copper will be needed to produce 10 liters of nitric oxide? Ans. 42.66 grams.

82. What volume of nitric oxide, measured at 743 mm. and 18° C., will be produced by treating 18 grams of metallic copper with an excess of nitric acid? Ans. 4.6 liters.

83. What weight of nitrogen tetroxide, N_2O_4, will result when 3300 cc. of nitric oxide, NO, is brought into contact with an excess of oxygen? Ans. 6.79 grams.

84. What weight of nitrous oxide, N_2O, will be formed by heating 50 grams of ammonium nitrate? Ans. 27.49 grams.

How many grams of water will be produced?

Ans. 22.50 grams.

85. What weight of ammonium nitrate must be taken to yield upon heating one liter of nitrous oxide? Ans. 3.58 grams.

86. What weight of ammonia, NH_3 will result upon decomposing 50 grams of ammonium chloride with slaked lime?

Ans. 15.92 grams.

87. What volume of ammonia may be obtained from 430 grams of ammonium chloride? Ans. 179.7 liters.

88. If one volume of water absorbs at 20° C. 650 volumes of ammonia, what weight of ammonia at 20° will be taken up by one liter of water at that temperature? Ans. 461.6 grams.

89. What weight of potassium hydroxide will neutralize 36.46 grams of hydrogen chloride? Ans. 56.1 grams.

90. What weight of sodium hydroxide will neutralize 36.46 grams of hydrogen chloride? Ans. 40 grams.

91. What weight of potassium hydroxide will neutralize 63 grams of nitric acid? Ans. 56.1 grams.

92. What weight of sodium hydroxide will neutralize 63 grams of nitric acid? Ans. 40 grams.

93. What weight of potassium hydroxide will neutralize 98 grams of sulphuric acid? Ans. 112.2 grams.

94. What weight of sodium hydroxide will neutralize 98 grams of sulphuric acid? Ans. 80 grams.

95. If 23 grams of sodium is thrown upon water, what weight of sodium hydroxide will be formed? Ans. 40 grams.

96. If 10 grams of metallic sodium is thrown upon water, what weight of sodium hydroxide will be formed?

Ans. 17.38 grams.

97. What weight of nitric acid will exactly neutralize 40 grams of sodium hydroxide? Ans. 63 grams.

98. If 40 grams of sodium hydroxide is dissolved in one liter of water, what weight of nitric acid will be required to neutralize 500 cc. of the solution? Ans. 31.5 grams.

99. If one liter of a solution of nitric acid in water contains 6.3 grams of the acid, what weight of sodium hydroxide will neutralize 20 cc. of the solution? Ans. 80 milligrams.

100. A solution of sodium hydroxide contains 20 grams of the substance in one liter. A solution of nitric acid contains 126 grams of the acid in one liter. How many cc. of the solution of sodium hydroxide will be required to neutralize 12 cc. of the acid?

Ans. 48 cc.

101. What weight of nitric acid will exactly neutralize the sodium hydroxide formed in No. 96, and what weight of sodium nitrate will result? Ans. 27.33 grams HNO_3.
36.90 grams $NaNO_3$.

102. What weight of sodium hydroxide will exactly neutralize a solution containing 34 grams of hydrogen chloride?
Ans. 37.36 grams.

103. What amounts of sodium hydroxide and hydrogen chloride would be needed to yield 75 grams of sodium chloride?
Ans. 51.36 grams NaOH.
46.74 grams HCl.

104. If one liter of a solution of sodium hydroxide contained 25 grams of sodium hydroxide, how many grams of nitric acid would be needed to exactly neutralize 60 cc. of the solution?
Ans. 3.3 grams.

105. If a sample of hydrochloric acid contains 44 grams of hydrogen chloride to the liter, how many cubic centimeters of the solution will be needed to neutralize 20 cc. of the solution of sodium hydroxide mentioned in the preceding question?
Ans. 14.48 cc.

106. What weight of sodium hydroxide will neutralize 98 grams of sulphuric acid? What weight of potassium hydroxide will neutralize the same? Ans. NaOH, 80 grams.
KOH, 112.2 grams.

107. If in neutralizing a certain amount of nitric acid with sodium hydroxide, 7.85 cc. of water is formed, how much nitric acid and how much sodium hydroxide have been employed?
Ans. 27.46 grams of HNO_3.
17.45 grams of NaOH.

108. How many grams of a 5 per cent. solution of KOH will be required to neutralize 10 grams of a 10 per cent. solution of H_2SO_4?
Ans. 22.9 grams.

109. 10 grams of commercial caustic soda, dissolved in water, required 116.3 grams of a 10 per cent. sulphuric acid to neutralize the solution. What percentage of NaOH did the substance contain? Ans. 95 per cent.

110. 10 grams of commercial nitric acid was exactly neutralized by the addition of 58.6 grams of a 10 per cent. solution of potassium hydroxide. What was the strength of the acid in HNO_3? Ans. 65.76 per cent.

111. If a solution contained 50 grams of ammonium hydroxide to the liter, how many cubic centimeters of hydrochloric acid containing 100 grams of hydrogen chloride to the liter will be needed to neutralize 60 cc. of the ammonium hydroxide solution?
Ans. 31.2 cc.

112. What weight of zinc sulphate will be formed upon treating 13 grams of zinc with sulphuric acid? Ans. 32.09 grams.

113. What weight of zinc sulphate will be formed when 98 grams of sulphuric acid acts on zinc? Ans. 161.37 grams.

114. What volume of chlorine can be obtained from 58.46 grams of salt? Ans. 11.1 liters.

115. How many liters of chlorine can be obtained from 34 grams of salt? Ans. 6.51 liters.

116. How much common salt will be needed to yield 10 liters of chlorine on treatment with manganese dioxide and sulphuric acid? Ans. 52.26 grams.

117. How many liters of chlorine can be obtained by treating 50 grams of manganese dioxide with hydrochloric acid?
Ans. 12.87 liters.

118. How much manganese dioxide will be required to liberate 13 liters of chlorine from hydrochloric acid?
Ans. 50.52 grams.

119. What weight of chlorine will be set free at the anode upon the electrolysis of a solution containing 65 grams of potassium chloride, KCl? Ans. 30.89 grams.

120. What weight of potassium hydroxide, KOH, would be formed in the preceding reaction? Ans. 48.93 grams.

121. What weights of salt, manganese dioxide and sulphuric acid would be required to produce one cubic meter of chlorine?
Ans. 3886.2 grams MnO_2.
5226.2 grams NaCl.
8761.8 grams H_2SO_4.

122. What weight of hydrogen chloride would result upon burning one liter of hydrogen in an atmosphere of chlorine?

Ans. 3.255 grams.

123. An ore contains 67.4 per cent. of manganese dioxide. What volume of chlorine would result upon treating one ton of this ore with hydrochloric acid? Ans. 157.47 cubic meters.

124. What weight of caustic potash will neutralize 100 liters of hydrogen chloride? Ans. 250.76 grams.

125. At 0° one volume of water will absorb 500 times its own volume of hydrogen chloride. How much will 500 grams of water at 0° increase in weight by absorbing hydrogen chloride to saturation? Ans. 407 grams.

126. What weight of hydrogen chloride can be obtained from 25 pounds of salt? Ans. 15.58 pounds.

127. What weight of sodium sulphate would be formed in the preceding reaction? Ans. 30.38 pounds.

128. What weight of hydrogen bromide would be neutralized by 40 grams of sodium hydroxide? Ans. 80.9 grams.

129. What weight of hydrogen iodide would be neutralized by 20 grams of sodium hydroxide? Ans. 63.96 grams.

130. What weight of hydrogen bromide would be formed by treating 18 grams of sodium bromide, NaBr, with dilute sulphuric acid? Ans. 14.15 grams.

131. What weight of hydrogen bromide would result if one cubic meter of hydrogen were caused to unite with bromine vapor by passing the mixture over a catalytic agent?

Ans. 7229.3 grams.

132. To obtain 15 grams of bromine how much manganese dioxide, potassium bromide and sulphuric acid should be used?

Ans. MnO_2, 8.16 grams.

KBr, 22.34 grams.

H_2SO_4, 18.40 grams.

133. To obtain 15 grams of iodine, how much manganese dioxide, potassium iodide and sulphuric acid will be required?

Ans. MnO_2, 5.14 grams.
KI, 19.63 grams.
H_2SO_4, 11.59 grams.

134. What weight of hydrogen fluoride, HF, would be evolved upon treating 36 grams of calcium fluoride, CaF_2, with sulphuric acid? Ans. 18.45 grams.

GAS VOLUMES AND MOLECULAR WEIGHTS

Equal volumes of gases (under identical conditions of temperature and pressure) contain the same number of molecules. (Avogadro's Hypothesis.) Consequently

(1) **The weights of equal volumes of gases are proportional to the molecular weights of the gases.**

Using hydrogen chloride and ammonia as an illustration:

36.468	:	17.034	=	1.628	:	.762
(Mol. wt. HCl)		(Mol. wt. NH_3)		(Wt. 1 liter HCl)		(Wt. 1 liter NH_3)

The molecule of oxygen contains two atoms; hence the molecular weight of oxygen is 32. If the weight of one liter of oxygen (1.429 grams) is known, the weight of a given volume of any gas of *known molecular weight* may be calculated, because the ratio between the molecular weights of oxygen and the gas in question will be the same as that between the weights of equal volumes of the two gases. For example, the weight of one liter of a gas of molecular weight 44 may be determined from the proportion

32	:	44	=	1.429	:	x
(Mol. wt. oxygen)		(Mol. wt. of other gas)		(Wt. 1 liter oxygen)		(Wt. 1 liter of other gas)

Expressed in other words—

(2) **The weight of one liter of any gas is equal to its molecular weight multiplied by** $\frac{1.429}{32}$

Conversely, if the weight of one liter of a gas is known, its molecular weight may be determined from the proportion
Wt. 1 liter oxygen: Wt. 1 liter of the gas =

Mol. wt. of oxygen : Mol. wt. of the gas,

(3) **The molecular weight of any gas is equal to the weight of one liter of it multiplied by** $\frac{32}{1.429}$

The density of a gas is frequently referred to air as unity instead of to oxygen. One liter of air weighs 1.293 grams and consequently is $\frac{1.293}{1.429}$ or .905 as heavy as oxygen. Since the molecular weight of oxygen is 32 and since (1) the molecular weights and the actual weights of equal volumes of gases are directly proportional,—

(4) **The molecular weight of a gas is equal to its density (referred to air) $\times$ (.905 $\times$ 32) = 28.96.**

One liter of oxygen weighs 1.429 grams. Its molecular weight is 32. A weight in grams of the gas equal to its molecular weight (i. e. 32 grams) will possess a volume (under standard conditions) of $\frac{32}{1.429}$ = 22.39 liters. In round numbers 22.4 liters.

Similarly, the molecular weight of hydrogen chloride in grams, divided by the weight of one liter of the gas, $\frac{36.468}{1.628}$ equals 22.4.

In the case of ammonia $\frac{17.03 \text{ (Mol. wt.)}}{.762 \text{ (Wt. 1 liter)}} = 22.4;$

nitric oxide $\frac{30.01 \text{ (Mol. wt.)}}{1.342 \text{ (Wt. 1 liter)}} = 22.4;$

hydrogen $\frac{2.016 \text{ (Mol. wt.)}}{.0899 \text{ (Wt. 1 liter)}} = 22.4;$

nitrogen $\frac{28.02 \text{ (Mol. wt.)}}{1.254 \text{ (Wt. 1 liter)}} = 22.4;$

These facts may briefly be expressed as follows:—

(5) **The volume occupied by the molecular weight of a gas in grams, under standard conditions, (termed the gram-molecular volume) is always the same, namely 22.4 liters.**

Now if $\frac{\text{molecular weight of a gas}}{\text{weight of one liter of the gas}} = 22.4$ it follows that $\frac{\text{molecular weight of a gas}}{22.4} =$ weight of one liter of the gas.

In other words,

(6) **The weight of one liter of a gas may be determined by dividing its molecular weight in grams by 22.4.**

135. How many liters of oxygen would be required to burn 10 liters of hydrogen sulphide? Ans. 15 liters.

136. What volume of oxygen would be required to burn 10 liters of marsh gas, CH_4? Ans. 20 liters.

137. What volume of oxygen would be required to burn 10 liters of carbon monoxide, and what volume of carbon dioxide would be formed?

Ans. 5 liters oxygen and 10 liters carbon dioxide.

138. How many liters of oxygen will combine with ten liters of nitric oxide, and what volume of nitrogen peroxide will be formed? Ans. 5 liters oxygen and 10 liters nitrogen peroxide.

139. If nitrogen and hydrogen could be made to combine completely, what volume of each would be required to form 10 liters of gaseous ammonia?

Ans. 5 liters nitrogen and 15 liters hydrogen.

140. What volume of hydrogen and of oxygen at 100° would combine to form one liter of steam?

Ans. 1 liter hydrogen; ½ liter oxygen.

141. What volume of hydrogen and of chlorine would combine to form 100 cc. of hydrogen chloride? Ans. 50 cc. of each.

142. In a eudiometer 88 cc. of hydrogen and 132 cc. of chlorine are exploded by a spark. What volume of hydrogen chloride is formed, and what volume of uncombined gas will remain?

Ans. 176 cc. hydrogen chloride, and 44 cc. chlorine.

143. What volume of oxygen is required to completely burn 10 liters of benzene vapor, C_6H_6? Ans. 75 liters.

144. What volume of oxygen is required to burn to carbon dioxide and water 1 liter of the vapor of alcohol, C_2H_6O?

Ans. 3 liters.

145. What volume of oxygen is required to completely burn 175 cc. of acetylene, C_2H_2? Ans. 437.5 cc.

146. If ammonia and chlorine react to form nitrogen and hydrogen chloride, what volume of chlorine is required to completely react with 6 liters of ammonia and what volume of nitrogen and hydrogen chloride result? Ans. 9 liters chlorine.
3 liters nitrogen.
18 liters hydrogen chloride.

147. If there is introduced into a tube that contains 300 cc. of chlorine an amount of ammonium hydroxide more than sufficient to react with the chlorine, and the excess of ammonium hydroxide is then neutralized with dilute sulphuric acid, what gas remains in the tube and what is its volume? Ans. Nitrogen. 100 cc.

148. Calculate the weight of one liter of each of the following gases, applying the method stated in (6) on page 28.

a. chlorine
b. nitrogen
c. sulphur dioxide
d. nitrous oxide
e. nitric oxide
f. ethane
g. butane
h. hydrogen chloride
i. carbon monoxide
j. carbon dioxide
k. marsh gas
l. phosphine

Applying the method stated in (3) on page 26, calculate the molecular weights of the following gases.

149. One liter of ethane weighs 1.342 grams.

150. One liter of hydrogen sulphide weighs 1.523 grams.

151. One liter of hydrogen bromide weighs 3.616 grams.

152. 232 cc. of phosphine weighs .3526 gram.

153. One liter of carbonyl chloride weighs 4.417 grams.

154. One liter of nitrous oxide weighs 1.969 grams.

155. 350 cc. of butane weighs .9079 gram.

Applying the method stated in (4) on page 27 calculate the molecular weights of the following gases:

156. The density (referred to air) of ammonia is .589.

157. The density (referred to air) of hydrogen fluoride is 0.691.

158. The density (referred to air) of bromine vapor is 5.525.

159. The density (referred to air) of mercury vapor is 6.98.

160. The density (referred to air) of gaseous hydrogen iodide is 4.417.

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161. Calculate the density (referred to air) of ethylene, C_2H_4.
Ans. .968.

162. Calculate the density (referred to air) of propane, C_3H_8.
Ans. 1.522.

163. Calculate the density (referred to air) of sulphur dioxide, SO_2. Ans. 2.213.

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164. How many liters of carbon dioxide would result from burning 5.384 grams of carbon? Ans. 10.046.

165. What volume of oxygen will be required to burn one kilogram of carbon? Ans. 1866.08 liters.

166. What volume of air, of 21 per cent. oxygen by volume, is needed to burn completely one ton of anthracite coal, assumed to be pure carbon? Ans. 8068.6 cubic meters.

167. If a candle consists of 85% of carbon and 15% of hydrogen, what weights of carbon dioxide and water will be formed when 25 grams of the candle burns? Ans. 77.91 grams CO_2.
33.51 grams H_2O.

168. What volume of carbon dioxide, measured at 750 mm. pressure and 20°C., will be formed when 17 grams of the candle, mentioned in the preceding question, is burned?
Ans. 29.32 liters CO_2.

169. If one liter of acetylene is burned, what volume of oxygen is necessary for the combustion and what volume of carbon dioxide will be formed? Ans. 2.5 liters oxygen.
2 liters carbon dioxide.

170. What weight of carbon dioxide would be obtained by burning 17 grams of carbon? Ans. 62.33 grams.

171. What volume of oxygen will unite with 730 cc. of carbon monoxide to form carbon dioxide, and what will be the volume of the carbon dioxide produced? Ans. 365 cc. oxygen.
730 cc. carbon dioxide.

172. What weight of carbon monoxide will result on heating 70 grams of oxalic acid, $H_2C_2O_4$, with concentrated sulphuric acid?
Ans. 21.77 grams CO.

173. What volume of water gas will be produced upon decomposing one ton of steam with hot coke?
Ans. 2256.2 cubic meters.

174. If 100 grams of oxalic acid is heated with concentrated sulphuric acid and the gases are passed through a solution of sodium hydroxide, what volume of carbon monoxide and what weight of sodium carbonate will result?
Ans. 24.86 liters CO.
117.86 grams Na_2CO_3.

175. With anthracite coal (assumed to be pure carbon), at $5.00 per ton, what will be the cost of the carbon necessary to produce 1000 cubic feet of water-gas, assuming that the reaction is as represented by the equation

$$C + H_2O = CO + H_2?$$

Ans. $0.042.

176. How much acetic acid, $C_2H_4O_2$, must be decomposed in order to obtain 10 liters of marsh gas? Ans. 26.81 grams.

177. From 10 pounds of pure limestone how many liters of carbon dioxide could be obtained? Ans. 1015.57 liters.

178. If 13 liters of carbon dioxide is passed through a solution of caustic potash, how many grams of potassium hydroxide will be converted into potassium carbonate? Ans. 65.2 grams.

179. If 100 grams of sodium carbonate is treated with hydrochloric acid, how many grams of salt, and how many liters of carbon dioxide (density referred to air = 1.52) will be formed?

Ans. 110.27 grams NaCl.
21.1 liters CO_2.

180. If one cubic meter of carbon dioxide is absorbed by lime-water, what weight of calcium carbonate will be formed?

Ans. 4470.37 grams $CaCO_3$.

181. A steel cylinder of four cubic feet capacity is to be filled with carbon dioxide under a pressure of 150 pounds to the square inch. What weight of marble and hydrogen chloride would be needed to produce the necessary amount of gas?

Ans. 5.06 kilograms $CaCO_3$.
3.69 kilograms HCl.

182. What per cent. of sulphur is contained in pure iron pyrites, FeS_2? Ans. 53.42.

183. What volume of sulphur dioxide would result from heating in the air one ton of pure iron pyrites, assuming that all of the sulphur in the pyrites is converted to sulphur dioxide?

Ans. 338.79 cubic meters.

184. What volume of hydrogen sulphide will be formed upon treating 40 grams of ferrous sulphide, FeS, with hydrochloric acid?

Ans. 10.17 liters H_2S.

185. What volume and what weight of sulphur dioxide will be formed upon burning one liter of hydrogen sulphide?

Ans. 1 liter SO_2.
2.86 grams SO_2.

186. If hydrogen sulphide and sulphur dioxide could be caused to react completely in the manner expressed by the equation

$$SO_2 + 2\,H_2S = 3\,S + 2\,H_2O,$$

what volume of sulphur dioxide and of hydrogen sulphide would be needed to liberate 96 grams of sulphur?

Ans. 22.4 liters SO_2.
44.8 liters H_2S.

187. If a solution containing 50 grams of lead nitrate, $Pb(NO_3)_2$, is precipitated by hydrogen sulphide, what will be the weight of the precipitate, PbS? Ans. 36.1 grams.

188. If a solution containing 50 grams of copper sulphate, $CuSO_4$, is precipitated by hydrogen sulphide, what will be the weight of the precipitate, CuS? Ans. 29.96 grams.

189. How much sulphuric acid could be produced from the sulphur dioxide arising from the combustion of one ton of sulphur? Ans. 3.06 tons.

190. How much sulphuric acid could be produced from the sulphur dioxide arising from the combustion of one ton of pure iron pyrites? Ans. 3268.6 pounds.

191. If 100 cc. of a solution of barium chloride that contains 20 grams of the salt in one liter is precipitated by sulphuric acid, what weight of barium sulphate will be formed? Ans. 2.24 grams.

192. An ore contains 62.38 per cent. of arsenopyrite, FeAsS. What weight of arsenic could be obtained by heating 500 pounds of the ore? Ans. 65.17 kilograms.

193. What volume of arsine, AsH_3, will result when 150 milligrams of arsenic trioxide, As_2O_3, is acted upon by nascent hydrogen? Ans. 33.92 cc.

194. What weight of arsenic would be obtained by reducing 157 grams of arsenic trioxide with charcoal? Ans. 118.939 grams.

195. What is the per cent. of boron in crystallized borax, $Na_2B_4O_7 \cdot 10H_2O$? Ans. 11.51 per cent.

196. What is the per cent. of silicon in quartz? Ans. 47.02 per cent.

197. What weight of silicon tetrafluoride, SiF_4, could be obtained by treating 430 grams of silica, SiO_2, with hydrofluoric acid? Ans. 743.24 grams.

198. If 275 grams of silica is fused with an excess of potassium carbonate, what weight of potassium silicate, K_2SiO_3, will result? Ans. 704.34 grams.

199. From 1500 pounds of salt how many kilograms of sodium carbonate can be obtained by the Leblanc process? How much charcoal and how much limestone will be required?

Ans. $Na_2CO_3 \cdot 10\ H_2O$ = 1666.18 kilograms.
$CaCO_3$ required = 582.63 kilograms.
Carbon required = 139.69 kilograms.

200. What weight of calcium sulphide will be produced in the manufacture of one ton of dry sodium carbonate by the Leblanc process? Ans. 1360.22 pounds.

201. What weights of salt, ammonia, and carbon dioxide will be necessary to produce one ton of sodium bicarbonate by the Solvay process? Ans. 1391.89 pounds NaCl.
405.29 pounds NH_3.
1046.89 pounds CO_2.

202. What weight of anhydrous sodium carbonate will result from heating 500 grams of sodium bicarbonate?
Ans. 315.55 grams.

203. What weight of washing powder ("sal soda") would be needed to furnish 125 grams of anhydrous sodium carbonate?
Ans. 337.25 grams.

204. What is the per cent. of sodium in Glauber's salt?
Ans. 14.30.

205. What would be the volume, under standard conditions, of the gases evolved from a mixture of 10 grams of potassium nitrate with such amounts of carbon and sulphur as are required by the equation:

$$2KNO_3 + 3C + S = 3CO_2 + N_2 + K_2S?$$

Ans. CO_2, 3.320 liters.
Ans. N_2, 1.104 liters.

Total 4.424 liters.

206. How many pounds of quicklime and how many cubic meters of carbon dioxide would be formed by heating 5 tons of limestone? Ans. CaO, 5604.4 pounds.
CO_2, 1015.5 cubic meters.

207. How many pounds of water would be needed to slake 15 pounds of quicklime? Ans. 4.81 pounds.

208. In the changing of 500 pounds of calcium hydrate, in mortar, to calcium carbonate, how many pounds of water are produced? Ans. 121.53 pounds.

209. How much Plaster of Paris, $(CaSO_4)_2 \cdot H_2O$, will result from heating 100 kilograms of gypsum? Ans. 84.3 kilograms.

210. How much quicklime and how much coke are needed for the production of 100 pounds of calcium carbide?

Ans. 87.52 pounds CaO.
56.16 pounds carbon.

211. What volume of acetylene will be formed when 100 pounds of calcium carbide is treated with water?

Ans. 15.856 cubic meters.

212. How many pounds of calcium carbide will be necessary to produce 1300 liters of acetylene when the temperature is 21°C. and the pressure is 745 mm.? Ans. 7.47 pounds.

213. How many liters of acetylene can be obtained from 50 grams of calcium carbide which is 93% pure, if the gas be evolved at a temperature of 40°C. and a pressure of 1½ atmospheres?

Ans. 12.41 liters.

214. What per cent. of magnesium oxide is contained in crystallized potassium magnesium sulphate, $K_2SO_4 \cdot MgSO_4 \cdot 6\ H_2O$?

Ans. 10.018 per cent.

215. How many pounds of zinc may be obtained from a ton of an ore containing 17.3 per cent. of zinc carbonate?

Ans. 180.4 pounds.

216. What weights of mercury and sulphur dioxide could be obtained from one ton of an ore carrying 53.78 per cent. of cinnabar? Ans. Hg, 927.0 pounds.
SO_2, 296.9 pounds.

217. What weight of aluminum oxide is contained in 100 pounds of potassium alum? Ans. 10.76 pounds.

218. What weight of aluminum oxide is contained in 100 lbs. of aluminum sulphate, $Al_2(SO_4)_3$? Ans. 29.84 lbs.

219. What weight of aluminum hydroxide will be produced when a solution containing 35 grams of potassium alum is precipitated with ammonium hydroxide? Ans. 5.76 grams.

220. What per cent. of aluminum does alum contain?

Ans. 6.6 per cent.

221. What weight of iron will result from the reaction of 5 kilograms of thermit; $2\ Al + Fe_2O_3 = Al_2O_3 + 2\ Fe$?

Ans. 2.6 kilograms.

222. An ore contains 23.46 per cent. of stibnite, Sb_2S_3. What is the per cent. of antimony in the ore?

Ans. 16.756 per cent.

223. How much chrome alum could be made from 10 kilograms of chromite? Ans. 44.58 kilograms.

224. What weight of chrome yellow would be formed if a solution containing 430 grams of potassium chromate were precipitated with lead acetate? Ans. 714.4 grams.

225. What weight of potassium permanganate could be prepared from 10 kilograms of an ore containing 62% of pyrolusite?

Ans. 11.27 kilograms.

226. Potassium permanganate oxidizes a ferrous salt to a ferric salt thus:

$$2\ KMnO_4 + 10\ FeSO_4 + 8\ H_2SO_4 = 5\ Fe_2(SO_4)_3 + K_2SO_4 + 2\ MnSO_4 + 8\ H_2O.$$

How many grams of potassium permanganate would be needed to oxidize a solution that contains 15.19 grams of ferrous sulphate?

Ans. 3.16 grams.

227. If a solution of potassium permanganate contains 1.58 grams of the salt in one liter, what weight of ferrous sulphate would 10 cc. of the solution oxidize to ferric sulphate?

Ans. 75.9 milligrams.

228. How many tons of pure hematite would be needed for the production of 100 tons of iron in the blast furnace, assuming that 2.3% of the iron in the ore passes into the slag?

Ans. 146.3 tons.

229. How much coke would be needed to reduce 50 tons of pure hematite, assuming that the reaction proceeds as follows:

$$2\ Fe_2O_3 + 3\ C = 4\ Fe + 3\ CO_2.$$

Ans. 5.63 tons.

230. An ore contains 36.4 per cent. of "ruby copper," Cu_2O. With what weight of charcoal (carbon) must 10 tons of the ore be heated in order to reduce all of the Cu_2O to metallic copper? ($Cu_2O + C = 2Cu + CO$.)

Ans. 610.05 pounds.

231. What weight of copper will be obtained in the preceding?

Ans. 6466.7 pounds.

232. A silver coin, containing 8 per cent. of copper, weighs 2.43 grams. If the coin be dissolved in nitric acid, how many grams of sodium chloride will be required to precipitate all of the silver as silver chloride? Ans. 1.21 grams.

233. In the preceding, what weight of iron will be required to reduce the silver chloride formed to metallic silver?

Ans. .58 gram.

What will be the weight of silver obtained?

Ans. 2.235 grams.

CALCULATION OF FORMULA FROM PERCENTAGE COMPOSITION AND DENSITY

The formula of a compound of known percentage composition may be ascertained by dividing the percentage amount of each element by the atomic weight of that element. There will thus be obtained a series of numbers that are to each other as the numbers of atoms of the different elements in the compound.

For example, oxalic acid has the following composition:

Carbon	26.66 per cent.
Hydrogen	2.24 per cent.
Oxygen	71.1 per cent.

Dividing each of these percentages by the atomic weight of the element concerned—

$$\begin{aligned} \text{C } 26.66 \div 12 &= 2.22 \\ \text{H } 2.24 \div 1.008 &= 2.22 \\ \text{O } 71.1 \div 16 &= 4.44 \end{aligned}$$

These resulting numbers are to each other as 1 : 1 : 2. The simplest formula is, then CHO_2. The true formula may be this or some multiple of it, as $C_2H_2O_4$, or $C_3H_3O_6$, etc. To know which is correct, the molecular weight of the compound must be ascertained.

It sometimes happens that the above method gives fractional ratios between the atoms. For example, red lead has the following composition:

Lead	90.65 per cent.
Oxygen	9.35 per cent.

$$\begin{aligned} 90.65 \div 206.9 &= .438 \\ 9.35 \div 16 &= .584 \end{aligned}$$

The ratio is here .438 : .584 or 1 : 1.33.

In such a case we multiply by such a number as will clear the ratio of fractions. In the example just given, where the ratio is 1:1.33 both numbers are multiplied by three, and we thus obtain the ratio 3 : 4. The formula of red lead is therefore Pb_3O_4.

234. What is the simplest formula of a substance that consists of oxygen, 88.809 per cent., and hydrogen, 11.191 per cent?

Ans. H_2O.

235. Calculate the simplest formula of a mercuric oxide that contains 92.593 per cent. of mercury and 7.407 per cent. of oxygen.

Ans. HgO.

236. What is the simplest formula of a substance consisting of calcium, 29.451 per cent., sulphur, 23.545 per cent., and oxygen 47.004 per cent? Ans. $CaSO_4$.

237. The percentage composition of a mineral is found to be: calcium, 40.06 per cent.; carbon, 11.99 per cent.; and oxygen, 47.95 per cent. What is its simplest formula?

Ans. $CaCO_3$.

238. Alcohol is found to have the following composition: C, 52.12 per cent.; O, 34.75 per cent.; H, 13.13 per cent. The density (referred to air) of alcohol vapor is 1.595. What is the formula of the substance? Ans. C_2H_6O.

(Calculating the formula by the method explained on page 38, it will be found that the simplest formula for alcohol is C_2H_6O, but, as explained above, the true formula may be this or some multiple of it, as $C_4H_{12}O_2$, $C_6H_{18}O_3$, etc. To ascertain which of these formulas is the true one, compute the molecular weight of the compound from the density of alcohol vapor (see (4) p. 27.) $1.595 \times 28.96 = 46.19$. The calculated molecular weights corresponding to the three possible formulas suggested above are—

$C_2H_6O = (2 \times 12) + 6 \times (1.008) + 16 = 46.048$
$C_4H_{12}O_2 = (4 \times 12) + (12 \times 1.008) + (2 \times 16) = 92.096$
$C_6H_{18}O_3 = (6 \times 12) + (18 \times 1.008) + (3 \times 16) = 138.144$

The molecular weight computed from the vapor density, 46.19, agrees more closely with the first of the calculated molecular weights than with any of the others. Consequently, C_2H_6O is accepted as the true formula of alcohol).

239. The percentage composition of acetic acid is carbon 39.98 per cent., hydrogen 6.72 per cent., and oxygen 53.30 per cent. What is the simplest formula that could be given to the substance?

Ans. CH_2O.

240. It is found, however, that the density (air) of acetic acid vapor is 2.079. What then, is its true formula?

Ans. $C_2H_4O_2$.

241. What will be the formula of a hydrocarbon which contains twice as many atoms of hydrogen as of carbon, and the vapor of which has a density (air) of 1.947? Ans. C_4H_8.

242. What is the formula of a hydrocarbon which contains an equal number of hydrogen and carbon atoms, and the vapor of which has a density (air) of 2.712? Ans. C_6H_6.

243. Formic acid has the composition: C, 26.08 per cent.; O, 69.54 per cent.; H, 4.38 per cent. The density (air) of its vapor is the same as that of alcohol: what is its formula?

Ans. H_2CO_2.

244. Aldehyde has the following percentage composition: C, 54.50 per cent.; H, 9.16 per cent.; O, 36.34 per cent. The density (air) of its vapor is 1.526. What is its formula?

Ans. C_2H_4O.

245. Butyric acid has the same percentage composition as aldehyde, but the density (air) of its vapor is 3.052. What is its formula? Ans. $C_4H_8O_2$.

246. A compound has the following percentage composition: carbon, 37.46 per cent.; hydrogen, 12.59 per cent.; oxygen, 49.95 per cent. One liter of its vapor weighs 1.4339 grams. What is its formula? Ans. CH_4O.

247. A gas has the following composition: carbon, 27.272 per cent.; oxygen, 72.727 per cent. Its density (air) is 1.52. What is its formula? Ans. CO_2.

248. A compound has the following percentage composition: oxygen, 76.17 per cent.; hydrogen, 1.6 per cent.; nitrogen, 22.23 per cent. One liter of its vapor weighs 2.817 grams. What is its molecular weight and formula? Ans. 63.018 and HNO_3.

249. A hydrocarbon consists of carbon 93.703 per cent.; hydrogen, 6.296 per cent. The density (air) of its vapor is 4.456. What is its formula? Ans. $C_{10}H_8$.

250. A gas has the following composition: nitrogen, 30.45 per cent.; oxygen, 69.55 per cent. One liter of the gas weighs 2.058 grams. What is its molecular weight and formula?

Ans. 46.01 and NO_2.

251. A compound has the following percentage composition: H, 1.19 per cent.; O, 56.84 per cent.; Cl, 41.97 per cent. One liter of its vapor weighs 3.771 grams. What is its molecular weight and formula? Ans. 84.458 and $HClO_3$.

252. A compound has the following composition: phosphorus, 2.22 per cent.; oxygen, 10.43 per cent.; chlorine, 69.35 per cent. The density (air) of its vapor is 5.295. What is its formula?

Ans. $POCl_3$.

253. A compound has the following percentage composition: I = 96.70 per cent.; C = 3.045 per cent.; H = .255 per cent. The density (air) of its vapor is 13.595. What is its formula?

Ans. CHI_3.

254. A compound has the following compositions: phosphorus 22.57 per cent.; chlorine, 77.43 per cent. One liter of its vapor weighs 6.131 grams. Calculate its molecular weight and formula. Ans. 137.35 and PCl_3.

255. At a temperature but little above its boiling point sulphur vapor is found to have a density of 6.675, while at 860° the density of the vapor is only 2.225. What conclusion would you draw in regard to the constitution of the sulphur molecule at these temperatures? Ans. S_6 and S_2.

CALCULATION OF ATOMIC WEIGHT FROM SPECIFIC HEAT

256. The molecular weight of potassium chloride is 74.6. The per cent. of potassium in the compound is 52.479. The specific heat of potassium is 0.166. What is the atomic weight of the element?

257. The molecular weight of lead oxide, PbO, is 222.9. The per cent. of lead = 92.821. Specific heat of lead = 0.031. What is its atomic weight?

258. A compound of hydrogen and sulphur has a molecular weight of 34. The per cent. of sulphur in the compound is 94.11. Specific heat of sulphur = 0.184. What is its atomic weight?

259. Analysis of uranium chloride shows the composition U = 62.713 per cent., Cl = 37.287 per cent. The specific heat of metallic uranium is 0.027. What is the atomic weight of uranium, and what the formula of the chloride? Ans. 238.5 and UCl_4.